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AUTHOR(S): Paul G. Weber

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Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

MASTER

A NEW RADIOMETER FOR EARTH RADIATION BUDGET STUDIES

Paul G. Weber
SST-7, D466, Los Alamos National Laboratory, Los Alamos, NM 87545

Abstract

A critical need for the U. S. Global Change Research Program is to provide continuous, well-calibrated radiometric data for radiation balance studies. This paper describes a new, compact, relatively light-weight, adaptable radiometer which will provide both spectrally integrated measurements and data in selected spectral bands. The radiometer design is suitable for use on (small) satellites, aircraft, or Unmanned Aerospace Vehicles (UAVs). Some considerations for the implementation of this radiometer on a small satellite are given.

Introduction

Understanding of climate changes demands, at the very least, accurate measurements of the radiative fluxes through the top of the atmosphere as a function of space and time, and covering the full range of ambient conditions. Indeed, a measure of the success of global circulation models (GCMs) is to compare the predicted energy balance from the codes with observations[1]. Information on the global radiation balance was provided by the Earth Radiation Budget Experiment (ERBE) instruments[2]. However, the ERBE scanners are no longer providing data, and the follow-on experiment, CERES, is scheduled to fly no earlier than 1997. Thus a large data gap exists in measuring the radiation balance at this critical time.

Another issue is to investigate radiative fluxes over a given site or region, combined with a full complement of measurements of ambient conditions. This would lead to a better understanding of the processes which underlie the observed fluxes, and to better parameterizations for inclusion into climate models. A site-specific study is being undertaken by the US DOE Atmospheric Radiation Measurements Program (ARM)[3], with the first site to be located in the mid-Western USA (Oklahoma / Kansas). Operation at this first site is scheduled to start in 1992. Further sites will be established in the Western Pacific Ocean, the North Slope of Alaska, and elsewhere, at annual intervals theraft :. One can chose satellite orbits which optimize coverage over such sites, or over particular regions. For a sufficiently small area, one could chose to make the relevant measurements using a high-flying aircraft.

This paper presents the design of the Los Alamos Radiometric Instrument (LARI): a new, compact, relatively light-weight, adaptable radiometer for these important measurements, together with some potential applications including operation on small satellites. The instrument includes well-calibrated total, shortwave, and contiguous, spectrally resolved channels, thus providing important information to the community[4]. The design allows implementation on a satellite, an aircraft, or Unmanned Aerospace Vehicle (UAV) with relatively minor modifications. However, the design philosophy for satellite, aircraft, and UAV radiometers is the same: namely, to provide a compact, low power, well-calibrated instrument with the desired spatial and wavelength coverages.

Experiment Design Considerations

Accurate measurements of the Earth's radiation balance are required for understanding of the processes controlling that balance. The measurement requirements are discussed in detail by the National Research Council's Committee on Earth Sciences (NRC/CES)[4]. The spectral coverage must include the range from about 0.3 to 4 μm for albedo studies, and approximately 4 to ≥ 50 μm for the longwave (thermal) flux. Some spectral resolution is desired to establish the actual composition of the atmosphere at the time of measurement. The required accuracy is extreme: as a simple basis, consider that doubling the CO_2 concentration in the atmosphere is predicted to have a net effect of only 2 - 4 $W{\cdot}m^{-2}$ compared to an annual average insolation of ~340 $W{\cdot}m^{-2}$ The mean accuracies suggested by the NRC/CES for the global radiation budget are 5% for the short-wave and 5 $W{\cdot}m^{-2}$ for the long-wave over annual cycles with 1-month resolution.

Because of variations in solar zenith angle, temperature, humidity, clouds and atmospheric composition, one wishes to make observations in sufficiently short timescales[5]. Continuity and overlap of measurements is also important to uncover any systematic offsets between satellite instruments. Thus, this problem is an excellent match to small satellites, with their attributes of relatively low cost and flexibility of launching. One can conceive of a set of three small satellites providing the appropriate diurnal and global coverage for the global radiation balance issue, or a similar set optimized for coverage of specific sites or regions.

LARI Instrument Description

The design of the Los Alamos Radiometric Instrument shown in Figure 1 is optimized for aircraft applications: the satellite version can be considerably simpler. (The aircraft version needs to operate in rather rapidly changing conditions as the aircraft flies through various conditions.)

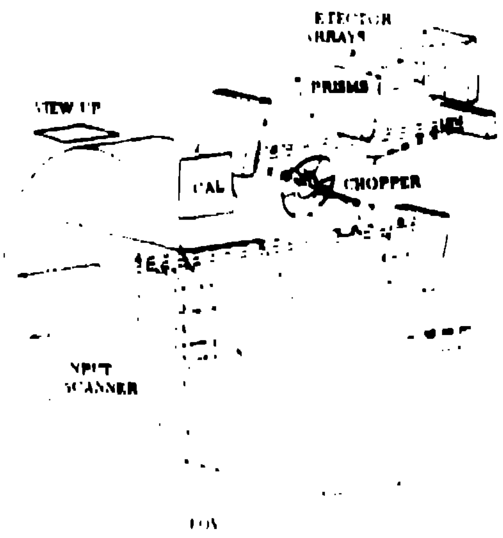

Fig. 1: Isometric view of the LARI instrument.

The input optic (lower left side of Fig. 1) consists of a pair of mirrors, mounted on a rotating scanner drum, and oriented at 45° to each other to provide almost complete cancellation of polarization effects. In addition to observing the desired scene, this scanner also accesses the on-board calibration sources (shown schematically as a rectangle near the scanner drum), thereby providing a complete instrument calibration on every scan. The modified Gregorian telescope determines the instantaneous field-of-view (IFOV) and allows physical separation between the input section of the telescope and the spectral analysis and detection volume (at the upper right of Fig. 1). These volumes are linked by a small aperture, allowing thermal and environmental stability for the prisms and detectors over long time-scales. A chopper is used at this aperture, since the pyroelectric detectors observe only *changes* in power: thus each individual measurement is referred to the chopper blade, with a full instrument calibration referenced to the on-board calibration sources on every complete rotation of the input optics scanner. Nominal design values for LARI in a ~800 km orbit include a nadir pixel size of 20-30 km, with cross-track scanning to 1500 km from nadir; the scan rate is sufficiently fast to spatially oversample. Various satellite maneuvres can be used to increase the viewing range of the instrument: one could, for example, rotate the satellite to obtain along-track scanning; such a data set would contribute to bi-directional reflectivity models.

After passing through the aperture, the radiation is recollimated, and then divided into several channels. The first channel is the total radiation channel, in which a geometrically determined fraction of the input power is directly focused on a detector, which measures the wavelength integral over the entire range of 0.2 to >50 μm (this range being determined by the characteristics of the optics and detectors). A parallel "short-wave" channel is identical, except the detector is filtered with a Suprasil (or similar) window, selecting radiation in the 0.2 to ~4 μm range. These two channels duplicate the functionality of the most frequently used ERBE channels; the wavelength-integrated long-wave radiation is typically obtained by subtracting the wavelength integrated short wave channel from the total.

While these two broad channels allow a separation of "solar" and "thermal" radiation, one requires spectral resolution to point to the causes of changes in these integrals. For example, with even crude spectral resolution, one can separate the black body equivalent temperature and the major absorption features due primarily to CO_2, O_2, O_3, H_2O, etc.. This radiometer includes this capability. Part of the radiation is dispersed by two side-by-side prisms, and is then incident upon a linear array of detectors, with the dispersion and detector dimensions chosen to give wavelength bands with specific dominant influences in each band. Figure 2 shows an example of such a selection: there are four contiguous bands (labelled 1,2,3,4) in the "short-wave"; plus five contiguous bands (labelled 5-9) in the "long-wave" region with dominant absorbing species indicated. The choices of spectral bands are, of course, limited by the available optical materials and by the detector characteristics. The two prisms are made of different optical materials, e.g. quartz and CsI to enable coverage of [illegible]

Light in the upper atmosphere can be highly polarized[9]. The LARI optical system is designed for low sensitivity to polarization: in addition to the polarization cancelling input scanner, the optics are used at small (near-normal) angles.

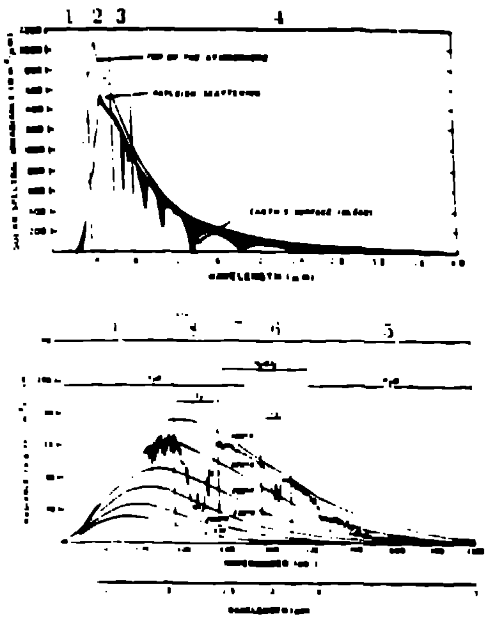

Fig. 2: Sample selection of contiguous wavelength bands.

Pyroelectric detectors have been chosen for a number of reasons. They are thermal detectors, which, with appropriate coatings, (see, e.g. Refs. 7 and 8) can cover the full wavelength region (0.2 - ≥ 50 μm) with uniform responsivity. They do not require cooling, the chopping frequency is selectable over a reasonable range, sensitivity is more than adequate for our application, and linearity is excellent. Electrical Substitution Radiometers using pyroelectric detectors have proven accurate at the < 1% level with excellent stability over many years[2]. Pyro-electric detectors have been used successfully both in space[10,11] and in aircraft radiometers[12]. Recent advances in material science and processing have permitted the production of both linear and two-dimensional arrays[13].

Accuracy of measurement is of paramount importance. The accuracy goal is one percent for the total and integrated short-wave channels. The radiometer will first be calibrated in a laboratory facility, using well-characterized blackbodies, tungsten lamps in an integrating sphere geometry, and other spectral sources. The calibrations will be ultimately referenced to a cryogenic electrical substitution radiometer[14], and to self-trapping photodiodes[15]. The details of the on-board calibrations are dependent on the specific application, but will consist of at least one blackbody (preferably two) plus lamp(s) for the shorter wavelengths. The calibrations require "state-of-the-art" equipment and techniques; they are facilitated slightly by the simultaneously available spectral information and built-in redundancy of checking that the sum of the spectrally resolved channels equals the total channels.

Data Products

As noted above, LARI is capable of fulfilling all of the requirements for radiation balance measurements as delineated in a number of studies. The instrument generates large quantities of data [illegible] which must be stored [illegible] at [illegible] ground stations, checked, archived and distributed to analysis centers. Analysis of ERBE data has demonstrated that a large amount of effort is required to translate radiometer data into a meaningful measurement of the fluxes at the top of the atmosphere[10].

Spacecraft Constraints.

The instrumentation implies several constraints on the satellite[17]. For example, LARI requires a three-axis stabilized platform, and nadir views with sufficient clear space to accomodate ± 60° cross-track scanning. Pointing control is specified here at ≤ 1 degree (3σ, each axis), while pointing knowledge is specified at ≤ 0.1 degrees (3σ, each axis). LARI has both a 15 rpm input optical scanner and a higher frequency chopper: these elements will cause some torques to be applied to the spacecraft from gyrospcopic effects.

The power requirements for LARI are relatively modest, with an estimated total 35 Watts regulated power. LARI detectors do not require cooling, and thermal control is relatively straight-forward.

The instrument digital processors will: monitor and control instrument operation and on-board calibration; acquire data, digitize, compress and store information; communicate with the satellite computer and send data to telemetry channels. It is anticipated that spacecraft processors and controllers will provide all other services.

Satellite Configuration

The actual design of a satellite system, and definition of a payload and support systems are beyond the scope of the present paper. Issues to be investigated include guidance, navigation and control; power systems; tracking, telemetry and command systems; data handling; thermal control; physical structure and payload integration.

Data Management and Distribution

It would be a convenience to have a single ground station for control and data receipt, as is done at Los Alamos for the small ALEXIS satellite. However, high speed ground links are being brought into operation at rates of 800 Mbits/s, which would require only seconds of transmission time per day to system nodes. Alternatively, one can use standard, slower, commercial communications systems. Handling the anticipated volume of data would be rather straight forward for a large integrated computing facility (ICF) such as exists at Los Alamos.

Data quality control, checking and integration are vital tasks. It would be appropriate to provide certain data to users in formats which are similar to those of ERBE, as well as enhanced data products, including, for example, spectrally resolved information. We hope to integrate our data into the climate change community as painlessly as is practicable.

Summary

The need for a continuous, accurate measurements of atmospheric radiation balance is well-documented. The use of compact instruments on small satellites provides an opportunity to address the physics of atmospheric radiative transfer. We have described the Los Alamos Radiometric Instrument, which is capable of providing the necessary broadband radiometric data in a timely fashion.

Acknowledgments

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